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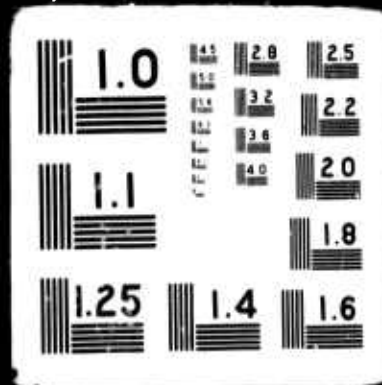
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TECHNICAL REPORT NO. 68-37

SHORT-PERIOD MULTICOMPONENT STRAIN SYSTEM  
Quarterly Report No. 2, Project VT/8704  
1 June to 31 August 1968

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GEOTECH  
A TELEDYNE COMPANY  
3401 Shiloh Road  
Garland, Texas

4 September 1968

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# ABSTRACT

The P'P'P' phase from a magnitude 8.2 earthquake was enhanced by suppressing 20-sec Rayleigh waves with the short-period vertical strain and vertical inertial seismograph combination at WMO. Signal enhancement by use of a continuous real-time spectral display of suppressed noise at WMO is not feasible in the frequency band 0.2-4.0 Hz because of a lack of time continuity of the spectral windows. True coherence of the seismic noise at WMO in the region of 1 Hz will remain indeterminable unless the ratio of seismic noise to system noise is substantially increased. Seismic noise at Garland, Texas, has been effectively suppressed by a matched combination of vertical strain and vertical inertial seismographs. In three independent series of field tests at WMO using two vertical strain seismometers in separate boreholes, loss of motion between fixed and free ends of the seismometer was approximately the same (22 percent). A comparison of motion produced at the fixed and free ends of the horizontal strain seismometer using an improved calibrator indicates an apparent loss of motion of about 20 percent between end points as compared with losses of 35 to 80 percent measured with the original calibrators.

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SHORT-PERIOD MULTICOMPONENT STRAIN SYSTEM  
Quarterly Report No. 2, Project VT/8704  
1 June to 31 August 1968

1. INTRODUCTION

This report discusses evaluation of a system of strain and inertial seismographs having matched amplitude and phase responses in the frequency range 0.01 to 10 Hz. It is submitted in compliance with Sequence Number A008 of Contract Data Requirements List, Contract F33657-68-C-0948. The Statement of Work is included as Appendix 1.

During the reporting period, the major accomplishments were as follows:

- a. In a series of three field tests using two vertical strain seismometers, loss of motion between fixed and free ends of the seismometer was determined to be approximately the same (22 percent).
- b. The new Electromagnetic Calibrator, Model 30240, which was tested recently on the east horizontal strain seismometer showed a marked improvement over the old calibrator. A comparison of motion produced at the fixed and free ends of the seismometer indicates an apparent loss of about 20 percent in the seismometer as compared to losses of 35 to 80 percent as measured on horizontal instruments in 1967.
- c. The P'P'P' phase from a magnitude 8.2 earthquake was enhanced by suppressing 20-sec Rayleigh waves with the short-period vertical strain and vertical inertial seismograph combination at WMO.
- d. It is concluded from a study of the spectra of suppressed seismic noise that signal enhancement by use of a continuous real-time spectral display of the suppressed noise at WMO is not feasible in the short-period range because of a lack of time continuity of the spectral windows.
- e. Seismic noise at Garland, Texas has been effectively suppressed by a matched combination of vertical strain and vertical inertial seismographs.

2. OPERATION (TASK 1a)

2.1 OPERATING PROBLEMS

The following problems, other than routine maintenance and calibration, prevented operation of all short-period (SP) and long-period (LP) channels

full time at WMO during this reporting period:

a. When both SP and LP channels are operated from one vertical strain seismometer, the S/N ratio of the SP channel decreases to a marginally acceptable level. Consequently, during the month of June, when one vertical strain seismograph (SZ1) was being used for calibration tests, no SP vertical strain data were recorded at WMO. The second seismometer furnished signal only to the LP vertical strain channel (SZL) in June.

b. During July, the SZL seismograph was not operated. This was due, in part, to lightning damage on 1 July and, in part, to the need for collecting some data simultaneously from both SP vertical strain seismographs.

c. In August, the vertical strain seismometer from the steel-cased borehole was removed for operation in Garland, Texas, whereas the remaining strain seismometer furnished signal for short-period operation at WMO. SP and LP vertical strain data were obtained from one seismometer from 3-10 August. Operation of the LP channel was discontinued indefinitely after 10 August because of the low S/N ratio of the SP channel resulting from the dual channel operation. Summed horizontal LP strain data will be used to obtain equivalent LP vertical strain data.

## 2.2 MAINTENANCE

A severe lightning storm on 31 May 1968 burned out three horizontal strain calibration coils, a short-period galvanometer, and the microbarograph, in addition to other damage at WMO. Coils were replaced and full operation was restored by 4 June 1968.

On 1 July 1968, lightning damaged one long-period and two short-period galvanometers, and the calibration coil recently replaced on the vertical strain seismometer in the plastic-cased borehole (SZ<sub>2</sub>B). Short-period instruments were repaired and placed in operation on the same date. The long-period vertical strain (SZL) galvanometer was replaced on 10 July. During the week of 8 July, the calibration coils on SZ<sub>2</sub>B and SZ<sub>1</sub>B were replaced, the latter having been damaged on 21 May.

## 3. DETERMINE OPTIMUM OPERATING CHARACTERISTICS (TASK 1c)

### 3.1 MATCHING OF STRAIN AND INERTIAL SEISMOGRAPHS

Short-period microseisms at WMO have not been effectively cancelled using a short-period vertical strain and inertial seismograph combination. When the present system was first installed at WMO, proper amplitude and phase matching of the vertical combination was verified by demonstrating effective cancellation of 0.5 to 1.0-second Rayleigh waves from a quarry blast. Uncontaminated Rayleigh waves from natural earthquakes are seldom registered on short-period seismographs. However, recently a magnitude 8.2 earth-quake in Japan produced well defined 15 to 20 sec Rayleigh waves on short period seismographs

at WMO. Proper matching of the vertical strain and inertial combination is demonstrated in figure 1 where Rayleigh waves are effectively cancelled.

### 3.2 SUPPRESSION OF LONG-PERIOD SEISMIC NOISE

Plans were firm for investigating suppression of long-period noise. Environmental noise limits the recording of long-period strain microseisms at a useful signal-to-noise ratio at WMO; however, some success might be attained with suppression of microseisms in the period band 6 to 15 seconds. Before useful data are available for the investigation, an additional operational amplifier must be placed in each long-period channel, in order to increase the ratio of seismic background noise to magnetic-tape noise.

### 3.3 LONG-PERIOD DETECTION CAPABILITY

A study of the detection capabilities of the long-period strain seismograph system is being conducted in order to evaluate the usefulness and limitations of the present system for studying the applications of long-period strain.

## 4. STRAIN APPLICATIONS (TASK 2a)

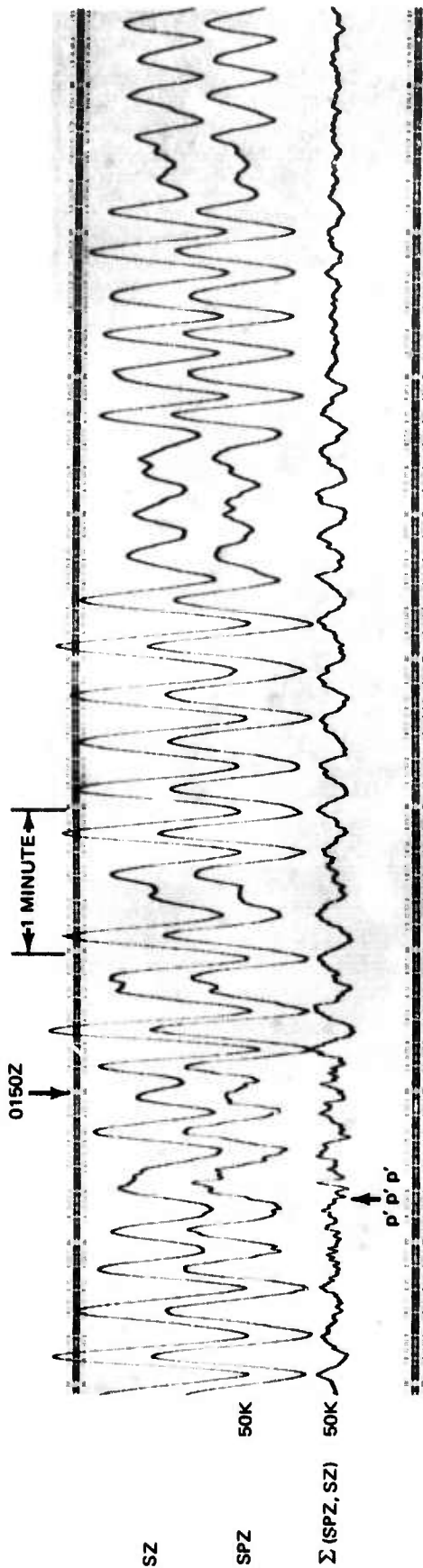
### 4.1 SUPPRESSION OF SEISMIC NOISE

The ability to suppress seismic noise at WMO with either a vertical strain or sum of two orthogonal horizontal strain (crossed strains) seismographs in combination with a vertical inertial seismograph has been investigated. Earlier studies, performed under contract 15288, showed that recordings of microseisms made by the vertical inertial in the short period range were incoherent with those made by strain seismographs except occasionally near a period of six seconds. The present investigation has been conducted in order, (1) to determine if there exist time-invariant windows in the microseismic spectra, such as possibly at 6 seconds, where the vertical inertial and strain seismograph recordings are coherent and may, therefore, be combined to suppress microseisms and, (2) to determine the degree of microseismic suppression over the entire short-period range, 0.1 to 4.0 Hz.

Six samples of microseisms recorded between 29 May 1967 and 14 November 1967 were used in the study. Both crossed strains (SXS) and vertical strain (SZ) recordings were subtracted from those made by the vertical inertial (SPZ). The relative amplitude levels of the recordings were established by equalizing the RMS value of strain recordings to those of the vertical inertial. Amplitude spectra of the SPZ and [(SPZ-(SZ or SXS))] recordings were then computed and their ratios calculated [(SPZ-(SZ or SXS))/SPZ]. Examples of the ratios, typical of all the samples examined, are shown in figure 2. Only in the range 0.1 to 0.16 Hz is there some consistency in seismic noise reduction, but even in this range, the degree of reduction changes from sample to sample.

These empirical results are in agreement with those suggested by estimates of coherence. This is illustrated in figure 3 where the ratios (SPZ-SXS)/SPZ;

MAG  
 @  
 1 Hz



SZ ≡ SHORT-PERIOD VERTICAL STRAIN SEISMOGRAPH  
 SPZ ≡ SHORT-PERIOD VERTICAL INERTIAL SEISMOGRAPH  
 Σ (SPZ, SZ) ≡ SUMMATION OF STRAIN AND INERTIAL CHANNELS, SUMMED IN OPPOSITION

WMO  
 RECORD NO. 137  
 16 MAY 1968

Figure 1. Seismogram illustrating effective cancellation of Rayleigh waves from a magnitude 8.2 earthquake by the matched vertical strain and inertial seismograph combination. Origin time = 00 48 55.4Z, 40.8N 143E,  $h = 7$  km,  $M_b = 8.2$  (Pas), off east coast of Honshu, Japan. Note enhancement of P'P'P'

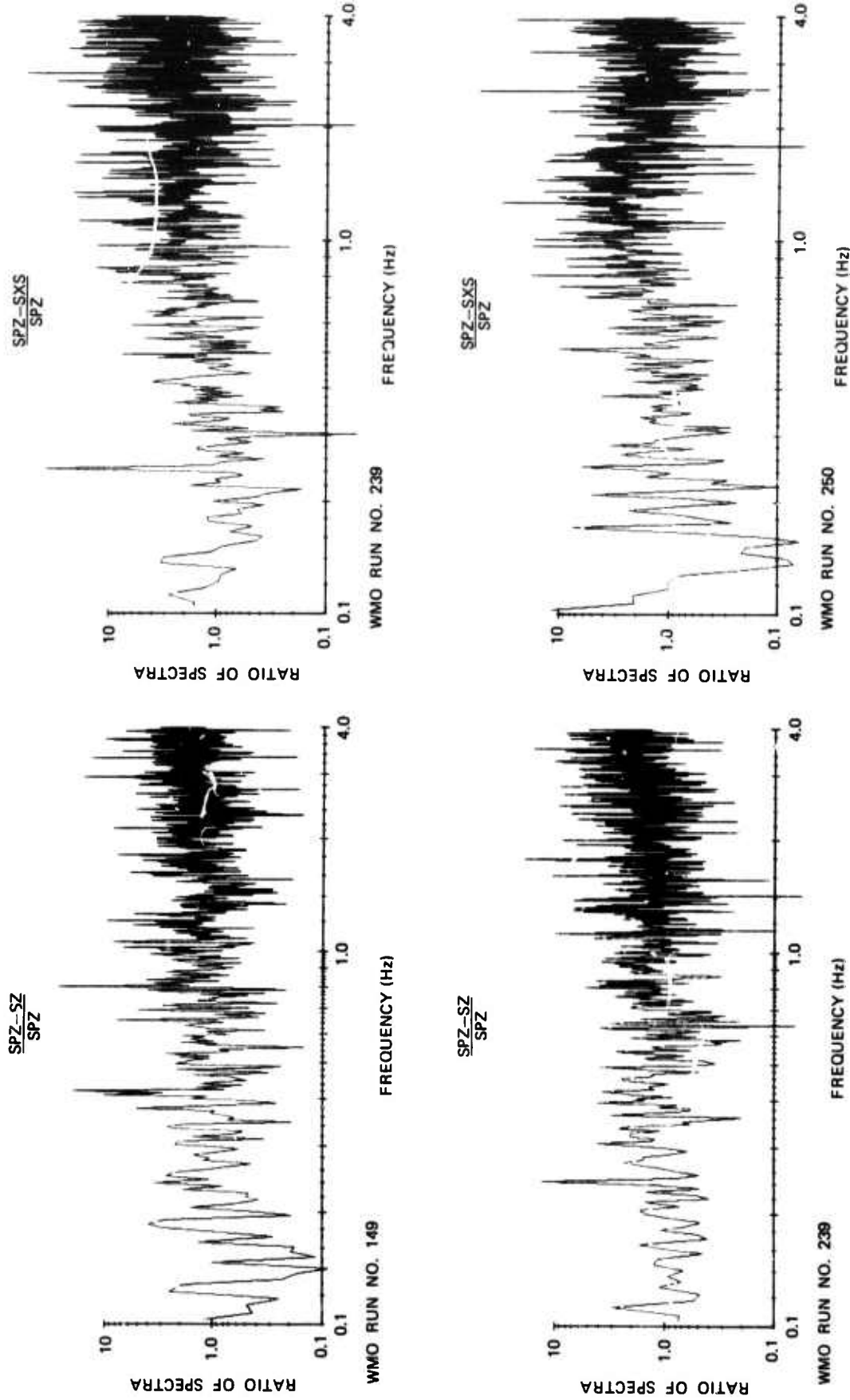
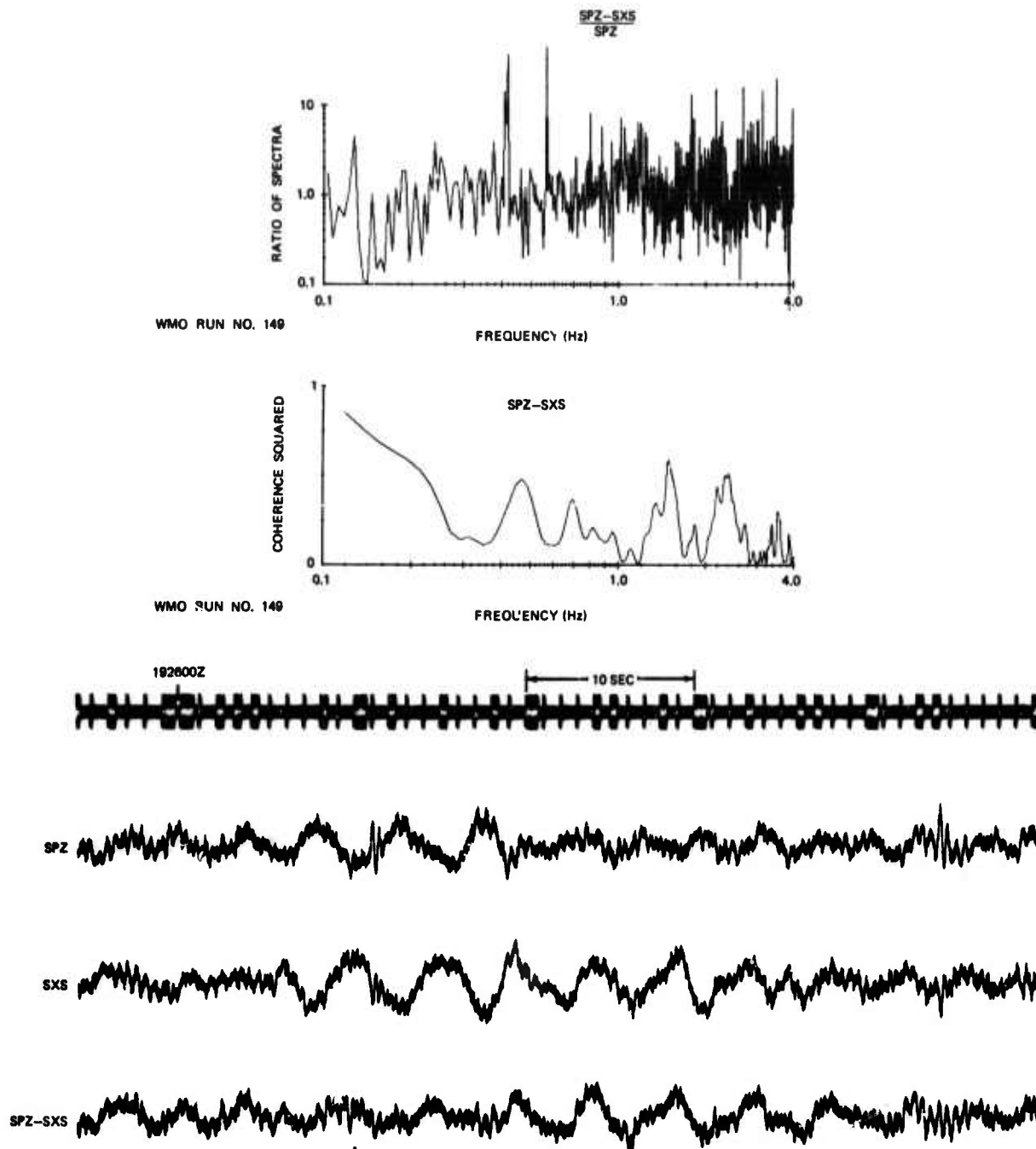


Figure 2. Ratios of the spectra of recordings by the vertical inertial (SPZ) minus either the vertical strain (SZ) or sum of two orthogonal horizontal strain (SXS) seismographs to the vertical inertial indicating suppression or addition of microseisms as a function of frequency



WMO  
RUN NO. 149  
29 MAY 1967

Figure 3. Ratio of the spectra of a recording by the vertical inertial (SPZ) minus the sum of two orthogonal horizontal strain (SXS) seismographs to the vertical inertial, coherence between the recordings by SPZ and SXS, and a part of the recordings used to compute the above ratios and coherence

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coherence squared between SPZ and SXS; and time domain display of SPZ, SXS and ESPZ-SXS are shown for one of the samples of microseisms examined. In this sample high coherence is observed between 0.12 and 0.22 Hz; similarly, noise suppression occurred in this range. From 0.22 to 4.0 Hz, the coherence is generally low except near 0.46, 1.5, and 2.4 Hz, and essentially no suppression occurred except near 0.46, 1.5 and 2.4 Hz.

In order to appreciate the degree of noise suppression, or lack of suppression, over the entire band, 0.1 to 4.0 Hz, the RMS values of the vertical inertial and inertial minus strain recordings were computed for all samples (table 1). From these values it becomes apparent that rather than suppress seismic noise, the combinations of strain and vertical inertial recordings increase the noise over the short period range 0.22 to 4.0 Hz. Only over one narrow window, 0.1 to 0.22 Hz, do the combinations show some limited potential.

#### 4.2 THE PROBLEM OF LOW COHERENCE IN THE REGION OF 1 HZ

Coherence computed between various strain seismograph recordings of microseisms has been observed to be low in a narrow frequency range near 1 Hz. This range correlates with a spectral low in microseisms and also a spectral high in strain seismograph system noise. This is indicated by figure 4. In figure 4a the ratios of the power spectra of recorded microseisms-to-system noise of the summation of the northeast and northwest strain seismographs are plotted as a function of frequency. Figure 4b shows the coherence squared computed between the above summation and the sum of the north and east strain seismograph recordings of the sample of microseisms. The correlation of coherence and signal-to-noise ratio is readily apparent. It should be noted that the ratios in figure 4a are necessarily of the power spectra of microseisms plus system noise-to-system noise  $[(S+N)/N]$  which may even be higher than the actual ratio of seismic noise-to-system noise  $(S/N)$ .

In order to demonstrate how low values of coherence may result from a low signal-to-noise ratio, as suggested by figure 4, the coherence between recordings of an earthquake signal was computed and is plotted as coherence squared in figure 5a. Samples of uncorrelated system noise were then added to the earthquake recordings and coherence was again computed, figure 5b. The signal-to-noise ratios of the power spectra were also determined, figure 5d, from which theoretical values of coherence squared were computed using the expression below given by Bendat and Piersol (1966):

$$\gamma_{xy}^2(f) = \frac{\gamma_{uv}^2(f)}{1 + (N_1/G_1) + (N_2/G_2) + (N_1/G_1)(N_2/G_2)}$$

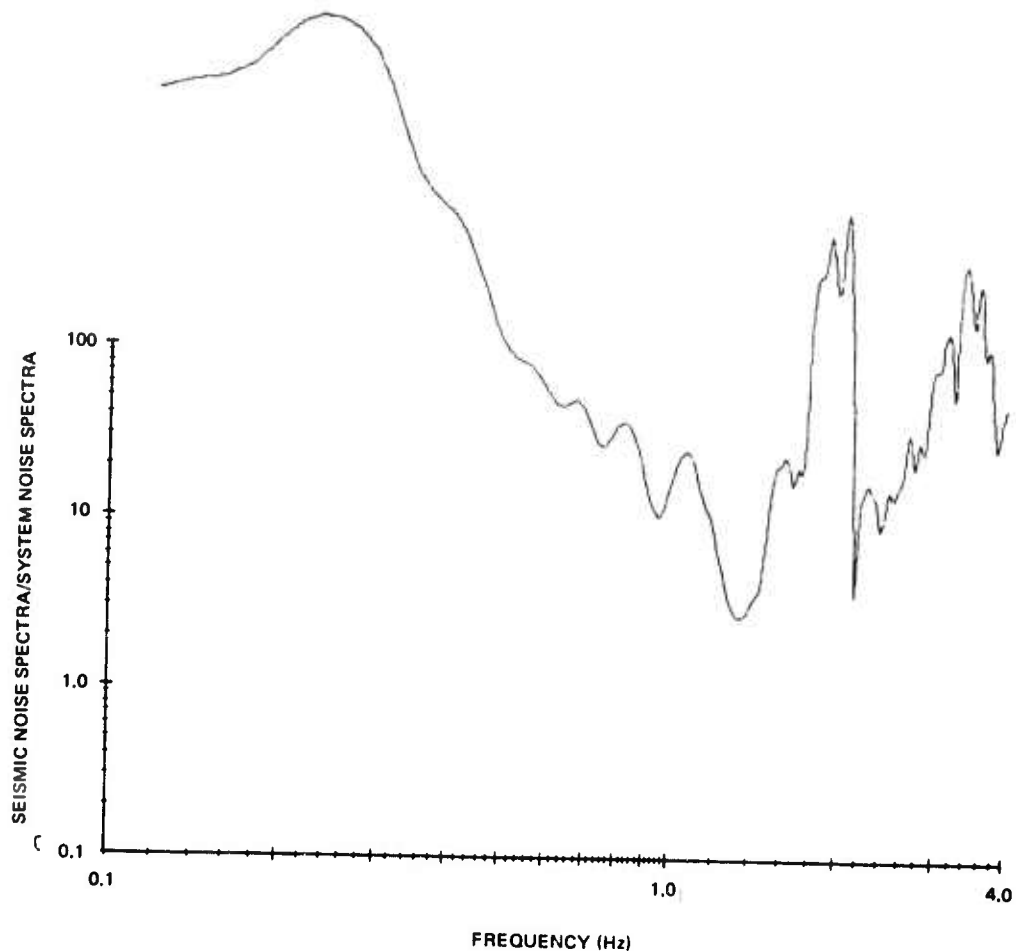
where  $\gamma_{xy}$  = coherence between earthquake recordings plus noise  
 $\gamma_{uv}$  = coherence between earthquake recordings  
 $N_1$  = power spectrum of noise on record 1  
 $N_2$  = power spectrum of noise on record 2  
 $G_1$  = power spectrum of earthquake signal on record 1  
 $G_2$  = power spectrum of earthquake signal on record 2

These results are illustrated in figure 5c. One will note that the theoretical values of coherence squared, figure 5c, are slightly lower than the actual values, figure 5b. This probably results from the assumption, made in the

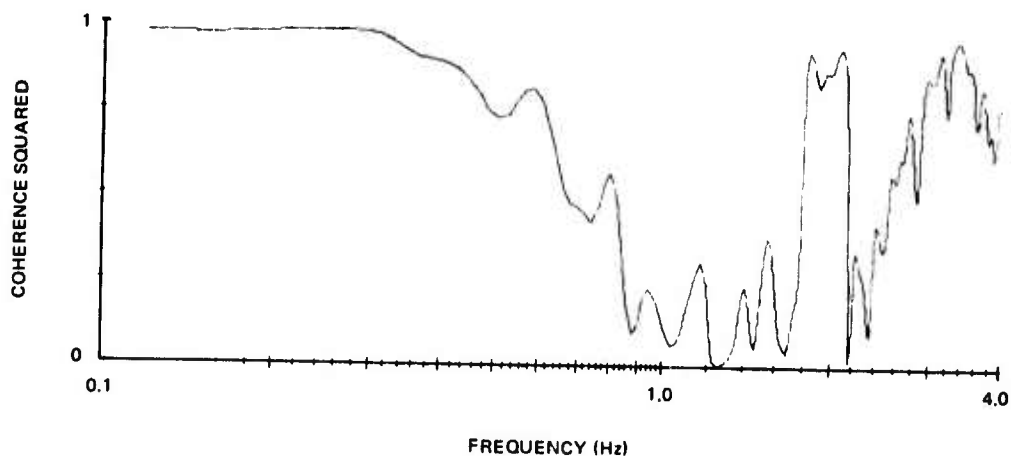
Table 1. RMS value of recordings by the vertical inertial (SPZ), vertical inertial minus vertical strain (SPZ-SZ), and vertical inertial minus the sum of two orthogonal horizontal strains (SPZ-SXS)

R M S

RUN NO. 1967	149	239	250	294	318 <sub>(1)</sub>	318 <sub>(2)</sub>
SPZ	2.14	1.31	1.87	1.38	1.53	0.84
SPZ-SZ	2.33	1.64	2.14	1.58	2.08	1.36
SPZ-SXS	2.14	--	2.91	1.53	1.89	1.10



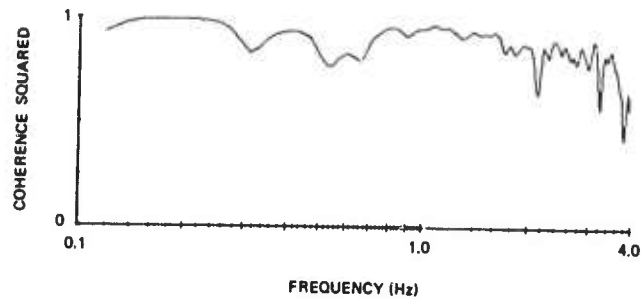
(a)



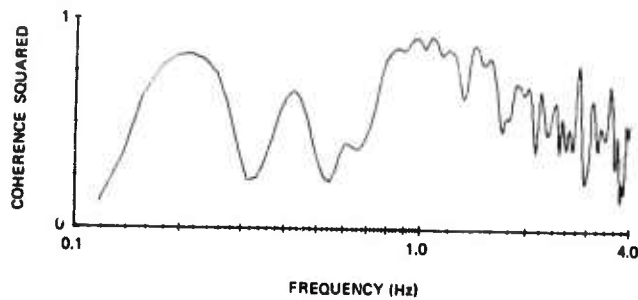
(b)

Figure 4. (a) Ratio of the power spectra of microseisms recorded by the northeast and northwest strain seismographs to seismograph system noise. (b) Coherence between the sum of the northeast and northwest and the sum of the north and east strain seismograph recordings of microseisms

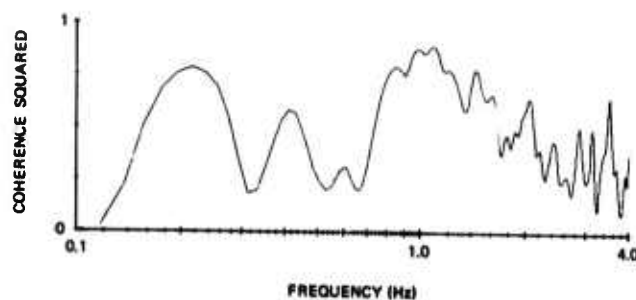
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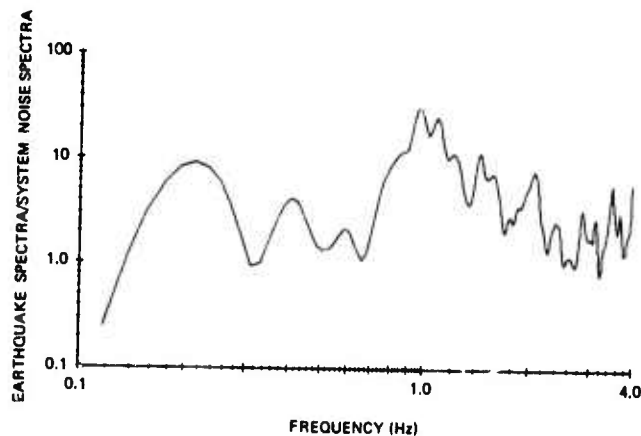
(a)



(b)



(c)



(d)

Figure 5. (a) Coherence between recordings of an earthquake P-wave (b) Coherence between recordings of the P-wave plus system noise (c) Approximation of the coherence between recordings of the P-wave plus system noise computed from signal-to-noise ratios and the values of coherence between the P-wave recording without system noise added (d) Ratio of the power spectra of a recorded P-wave to seismograph system noise

G 4341

derivation of the above expression, that the noise is completely additive. This expression does, however, give a very good approximation of the effect of a poor signal-to-noise ratio. Furthermore, it is seen that a computed estimate of coherence is greatly affected by signal-to-noise ratios.

Since the measured  $[(S+N)/N]$  of recorded microseisms by the northeast and northwest strain seismographs is low near 1 Hz, and will be even lower on the vertical strains, it is concluded that computed coherence between strain seismographs will always be low in that frequency range, that is, the true coherence of the microseisms will remain indeterminable unless the signal-to-noise ratios are substantially increased.

#### 4.3 WAVE IDENTIFICATION

Analysis of digitized strain and inertial recordings of earthquakes has commenced. Power spectra of some of the strain and inertial recordings and their phase relationships have been computed for 16 sec samples which include the P arrival. No conclusions have been drawn at this time.

Both time and frequency domain examination of each recorded earthquake phase will be made to determine if there exist diagnostic properties which might enable identification. Apparent phase velocity determinations and possible mode separation of surface waves will be studied.

Included among the earthquakes to be examined is the explosion 'BOXCAR', a large Nevada Test Site event.

#### 4.4 SURFACE EFFECT

Anomalous signals recording by a vertical strain seismograph located near the surface (3m) have been observed at WMO. Theoretical calculations show that in a layered half-space vertical differential displacement resulting from incident P or SV waves will differ from horizontal differential displacement both in magnitude and phase because of vertical inhomogeneities in the interval of measurement. In an attempt to determine if the anomalies were a result of layering, and if so, to establish an earth model that would provide more accurate theoretical predictions, the phase difference between four recorded P waves on the vertical and summed horizontal strain seismographs were examined using digital and analog techniques. The results are inconclusive due to the limited number of P waves examined. Unfortunately, the necessarily stringent requirements imposed on data for this examination, i.e., that only large magnitude earthquakes be used to assure a high signal-to-noise ratio on strain seismograms, and that the earthquakes be recorded at times when there was essentially no wind at WMO, combined with the relatively short period of time that a vertical strain was operated near the surface preclude a useful model resulting from this study. Therefore, no further effort will be expended.

#### 4.5 P-WAVE ENHANCEMENT

The body phase P'P'P' was enhanced by a combination of vertical strain and inertial seismograph outputs as it arrived coincidentally with the Rayleigh waves from the same large magnitude earthquake, (figure 1). This sample demonstrates that the above combination can be used to enhance longitudinal waves when the seismic background consists of essentially one mode of Rayleigh wave.

## 5. IMPROVEMENT OF INSTRUMENTS (TASK 2b)

### 5.1 VERTICAL STRAIN SEISMOMETER

In order to prevent strain member drag in the transducer package of the vertical strain seismometer, the transducer clamp mechanism was modified on both instruments at WMO. The modification entailed shortening two guide pins in each seismometer, increasing the free travel of the clamp link from 0.312 to 0.562 inch. Also, the guide ring on the top of the transducer package in the plastic-cased borehole was removed and three guide springs were installed. These springs provide sufficient force to insure that the package remains centered in the large diameter borehole. These modifications simplified seismometer installation and provided more reliable operation.

Following the above modifications, relative motion between fixed and free ends of both seismometers was measured using both a minimum interval and a normal 18.6 meter interval between anchors. The Model 30230 EM Calibrators were used to generate the motion. By comparing data from the two configurations, mechanical loss between the fixed and free ends of both seismometers was found to be approximately the same (22%) as measured in earlier tests. Also, the phase and amplitude responses of both seismometers showed little deviation from those in earlier tests which were reported in TR 68-22.

### 5.2 HORIZONTAL STRAIN CALIBRATION

After completion of laboratory tests, the engineering model of the Electromagnetic Calibrator, Model 30240, was installed on the east strain seismometer at WMO on 17 July. A photograph and sketch of the calibrator are shown in figures 6 and 7, respectively.

Field tests of the unit showed a considerable improvement over the existing two-coil calibrator. First, the calibration constant is approximately 100 times the old constant. This eliminates the need of a power amplifier to produce the high currents formerly necessary for calibration. Second, resonances caused by apparent unbalance in forces produced by the two coils of the old calibrator are reduced or eliminated. Figures 8 and 9 show the amplitude and phase responses, respectively, measured at both the fixed and free ends of the seismometer. These results show some improvement over those obtained during tests in 1967. Finally, comparison of motion produced at the fixed and free ends of the seismometer as shown in figure 7 indicates an apparent loss of about 20 percent as compared to losses of 35 to 80 percent as measured on horizontal instruments last year.

Minor modifications to facilitate installation were incorporated into the drawings, and fabrication of three additional calibrators was begun in mid-August.

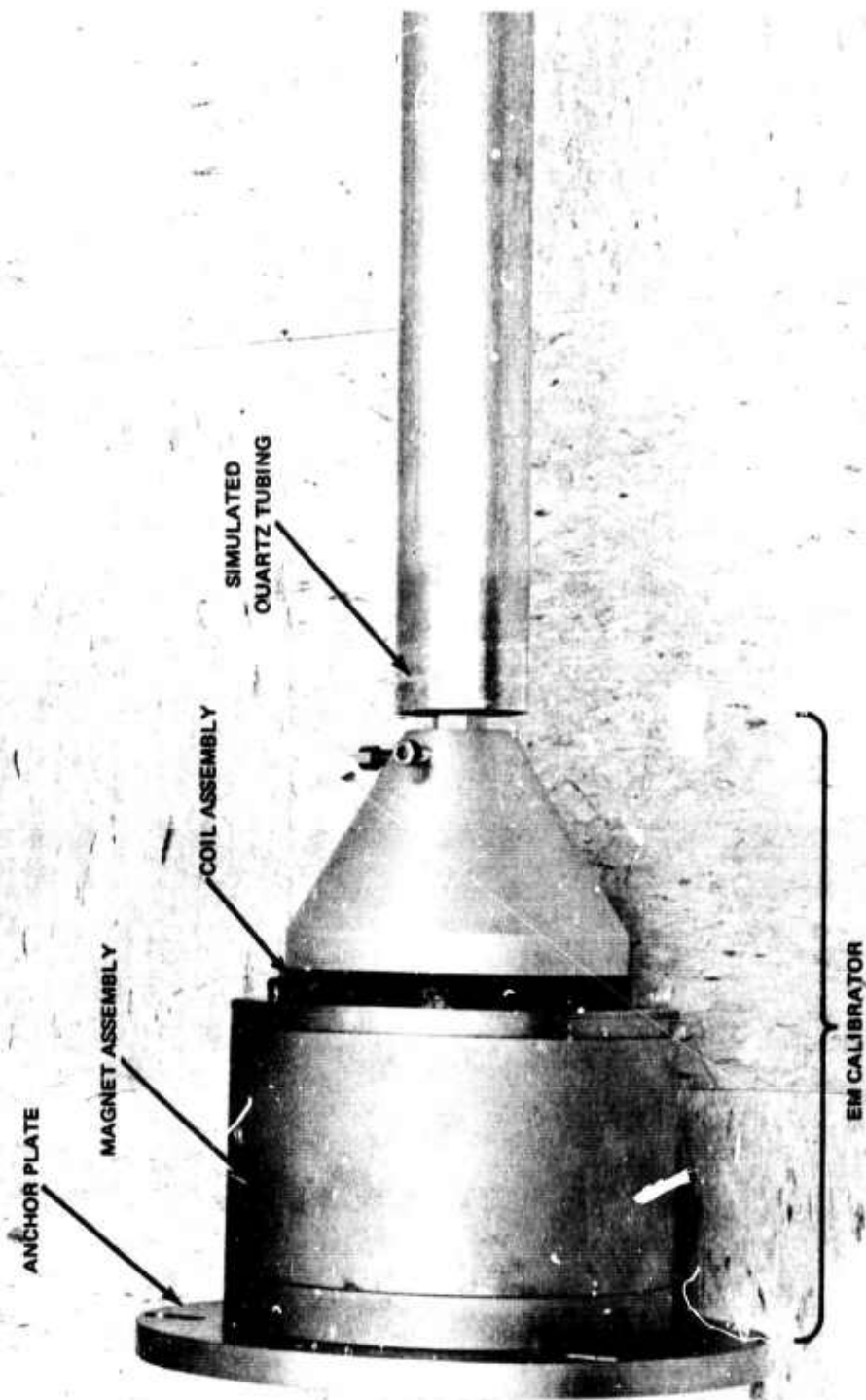


Figure 6. Laboratory mock-up of Model 30240 EM Calibrator for the horizontal strain seismometer

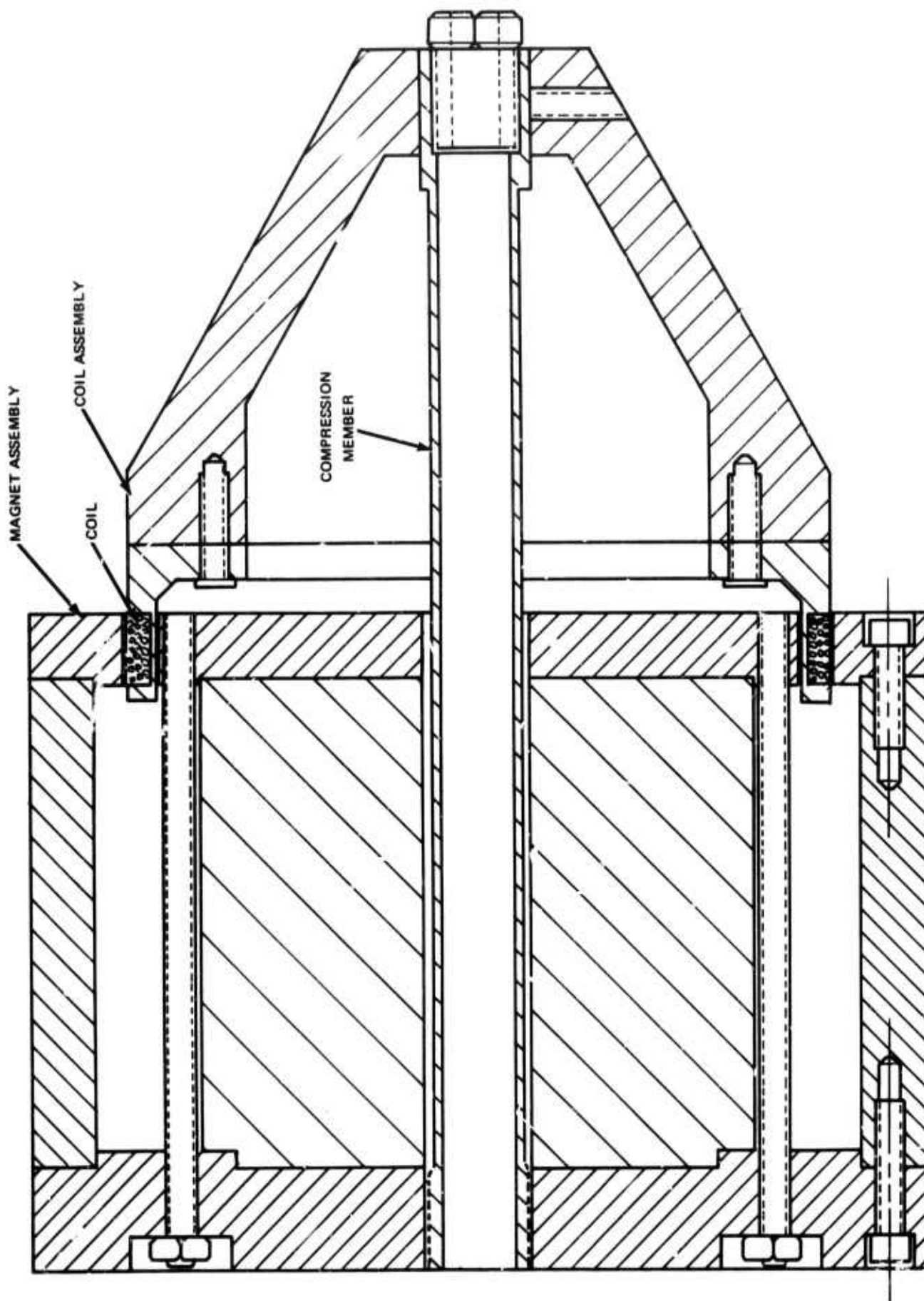


Figure 7. Full-scale sketch of Model 30240 EM Calibrator for the horizontal strain seismometer

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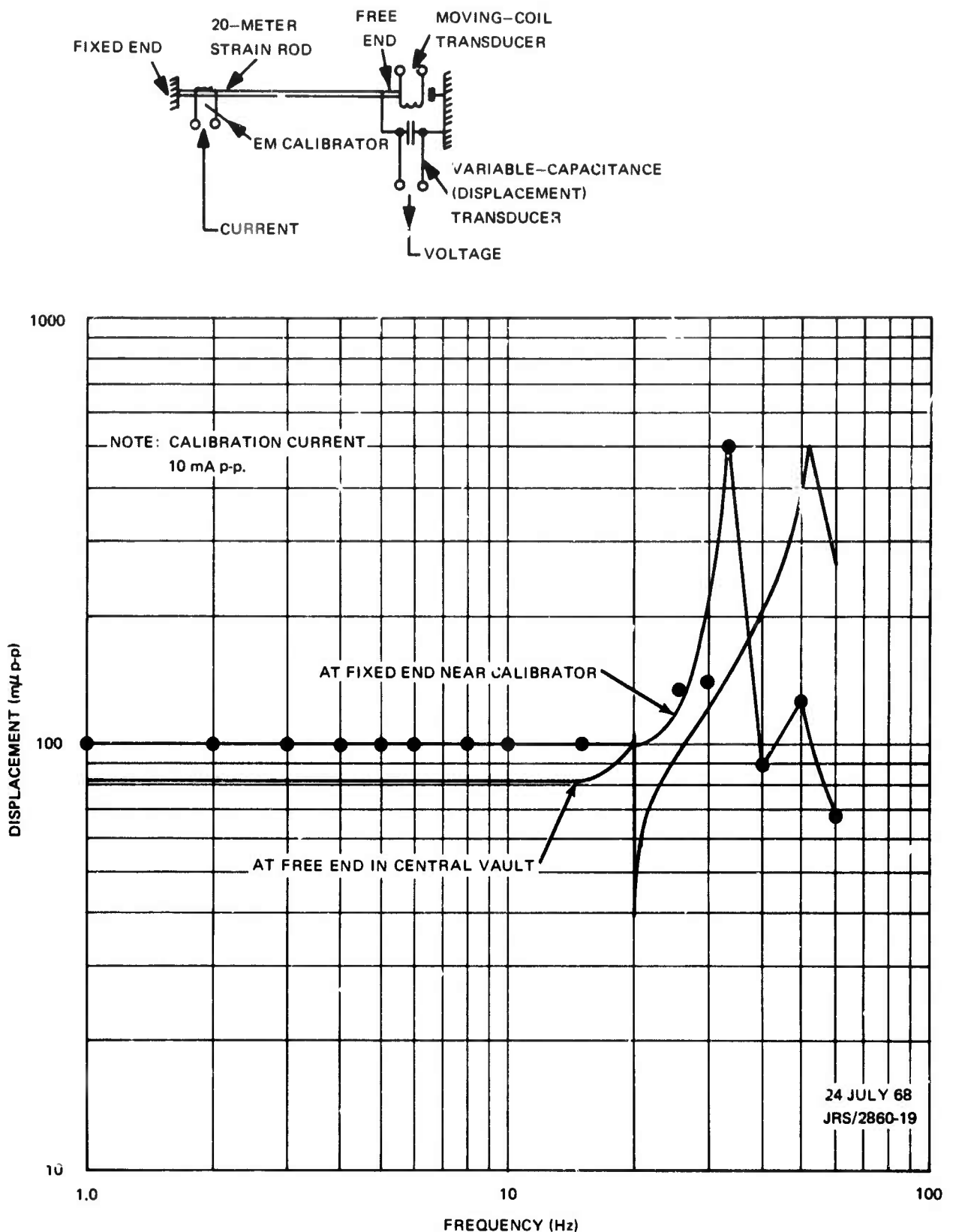


Figure 8. Amplitude response of east strain seismometer measured with a variable capacitance transducer at each end showing an apparent 20 percent loss in calibrator motion between fixed and free ends. Calibrator used was Electromagnetic Calibrator, Model 30240

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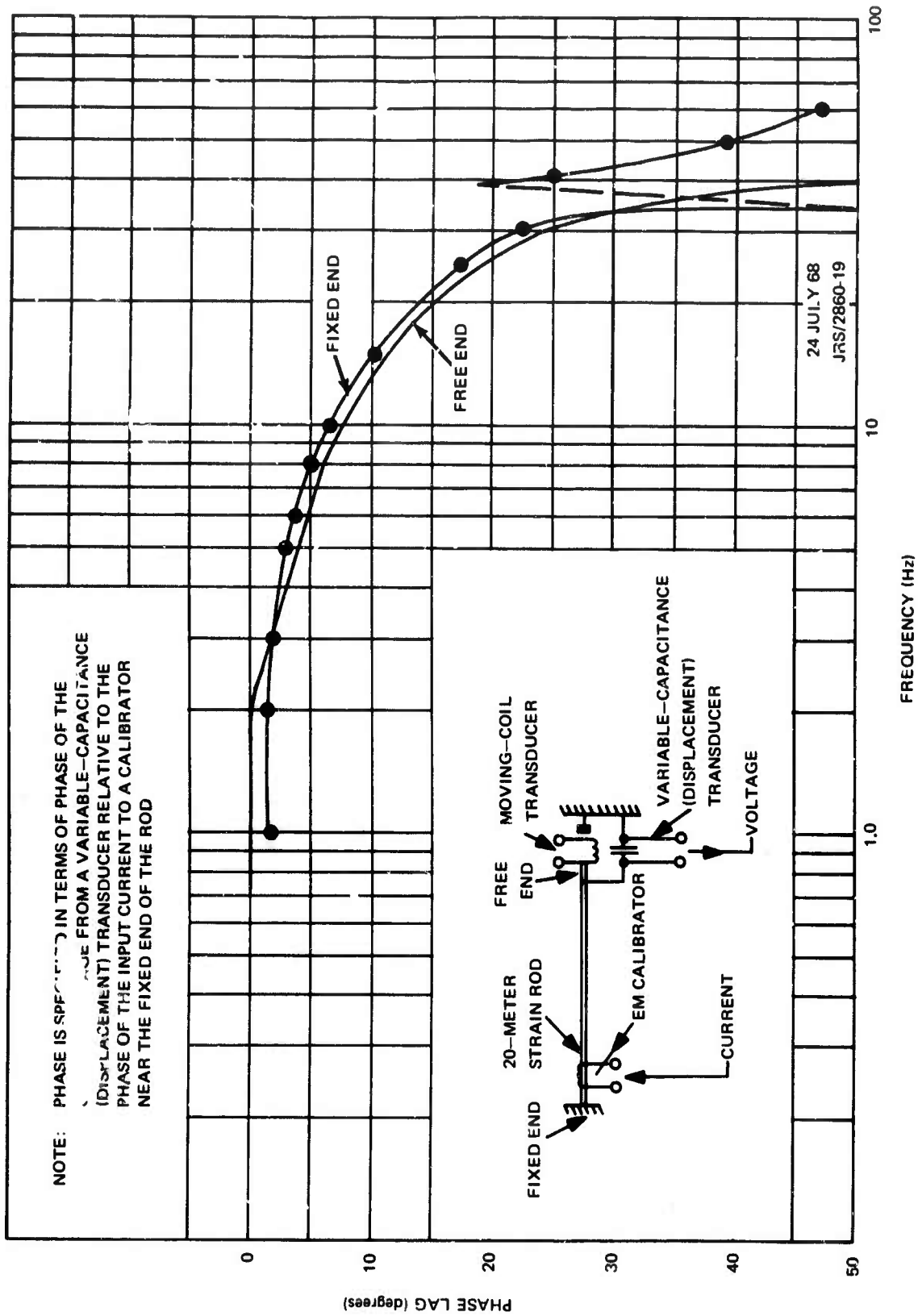


Figure 9. Phase response of east strain seismometer measured with a variable capacitance transducer showing phase lags at fixed and free ends of the seismometer

## 6. TEST NEW SITE (TASK 2c)

On 26 July, the vertical strain seismometer at WMO was removed from the steel-cased borehole and installed at a depth of 13.6 m in the 107 m borehole in Garland, Texas. Matched vertical strain and vertical inertial seismographs were in operation at Garland on 31 July in compliance with milestone requirements. Recording, monitoring, and calibration equipment are being furnished by the Model Station Test Facility as planned. On-line Develocorder records demonstrate substantial suppression of seismic noise and marked enhancement of P waves. A discussion of the Garland site, the instrumentation, and the test results follows.

The principal objective in evaluating a new site is to determine whether the detection capability at noisy sites containing essentially single mode Rayleigh waves can be improved by a vertical strain and inertial combination of seismographs. The idea of improving noisy sites was stimulated by failure to suppress microseisms at WMO, where the short-period noise field is complex and where low ratios of seismic noise to instrument noise exist in the region of 1 Hz.

In considering tests at Garland, as well as at other sites, power spectral density plots of seismic noise in the borehole at Garland, seismic noise at Cumberland Plateau Observatory (CPO), and system noise for the vertical strain seismograph were compared. Based on the ratio of seismic noise to system noise at each site, it was concluded that the Garland site is quite acceptable for tests on noise suppression, whereas, CPO is marginal at 0.8 Hz and 2.3 Hz. Compared with CPO, the Garland site during a very quiet period at night at a depth of 61 m in the borehole has 16 dB more seismic noise at 1 Hz and 25 dB more noise at 2 Hz.

The strain and inertial system at Garland contains the same components as used in operation at WMO. The differentiating effect inherent in strain seismometers and the response of a narrow band-pass filter combine to match the response of the inertial seismometer. The system is described in Geotech Technical Report No. 68-3, Final Report, Project VT/5081. In order to equate the response of strain and inertial seismographs to Rayleigh waves, a 90-Degree Phase Compensator, Model 15122, was used on-line at Garland. The phase compensator is an all-pass filter that produces a relative phase shift of 90 degrees between strain and inertial signals over a one-decade frequency band (0.2-2Hz) without altering the relative amplitude response in that range. The phase compensator deviates only about 15 degrees at 0.1 Hz and 20 degrees at 4 Hz and has a correspondingly gentle change in amplitude response beyond its flat range.

The uncompensated vertical inertial seismograph channel (SPZ) and the uncompensated vertical strain channel (SZ) are recorded on magnetic tape and Develocorder. The phase compensated channels SPZ\*, SZ\*, and  $\Sigma$ (SPZ\*, SZ\*) are also recorded on magnetic tape and Develocorder.

A seismogram showing marked suppression of seismic background noise and improved definition of first motion of a P wave on summation traces is shown in figure 10. The noise sample shown is typical of frequently occurring train noise at Garland.

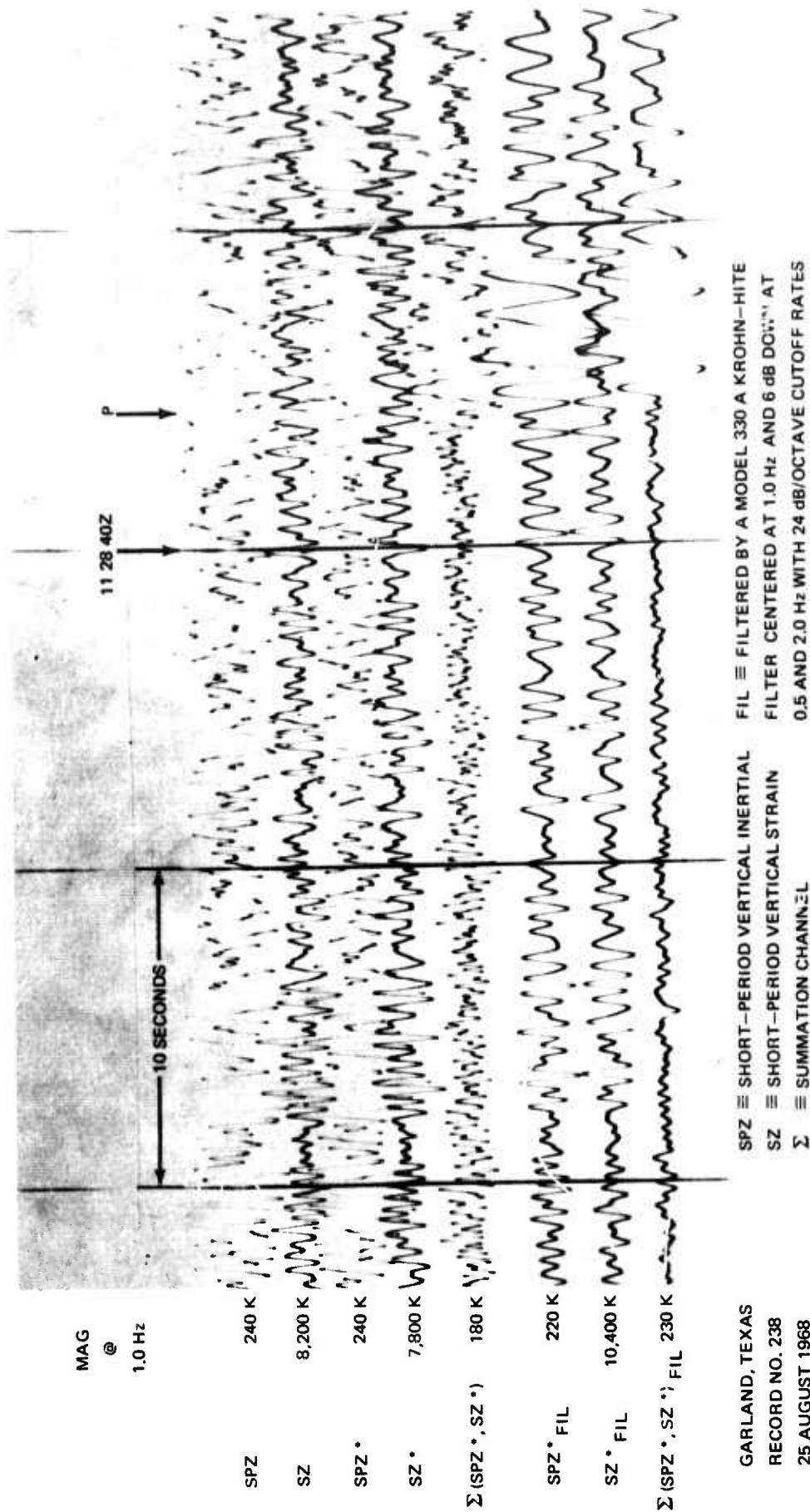


Figure 10. Seismogram showing marked suppression of seismic background noise and enhancement of P-wave using a vertical strain - vertical inertial seismograph combination at Garland, Texas

It is noted that the residual high frequency noise on  $\Sigma(\text{SPZ*}, \text{SZ*})$  is caused by the absence of high frequency noise on the strain channel ( $\text{SZ*}$ ). The latter condition is a result of the inherent non-linearity of frequency response as the length of the wave approaches the length of the seismometer. Residual high frequency noise may also occur on the  $\Sigma$  trace at frequencies higher than the designed operating range of the 90-degree phase compensator.

To prevent high frequency residual noise from deteriorating noise suppression near 1 Hz, a Model 330A Krohnwhite Filter peaked at 1.0 Hz and down 6 dB at 0.5 and 2.0 Hz was installed in each compensated channel. The improvement is evident in figure 10.

Suppression of low-level nighttime noise and enhancement of first motion of a P-wave at 031916 Z is demonstrated in figure 11.

Another example of noise suppression and P enhancement is shown in figure 12. The residual background noise on the  $\Sigma$  traces in figures 11 and 12 result from incomplete canceling of some frequencies and possibly addition of others. Further evaluation will be accomplished with power spectra of individual and summed traces. Some of the residual signal has been traced to wind noise generated by a utility pole located 6 meters from the strain borehole. Therefore, evaluation is limited to data obtained during wind-free periods. Vibration of the seismometer rod is another possible source of noise since the rod is not completely immersed in oil at present. An improvement in test conditions may be necessary to reduce residual noise on the summation trace.

## 7. REFERENCES

Bendat, Julius A., and Piersol, Allen G., 1966, Measurement and analysis of random data: New York, John Wiley and Sons, Inc., p 215-216.

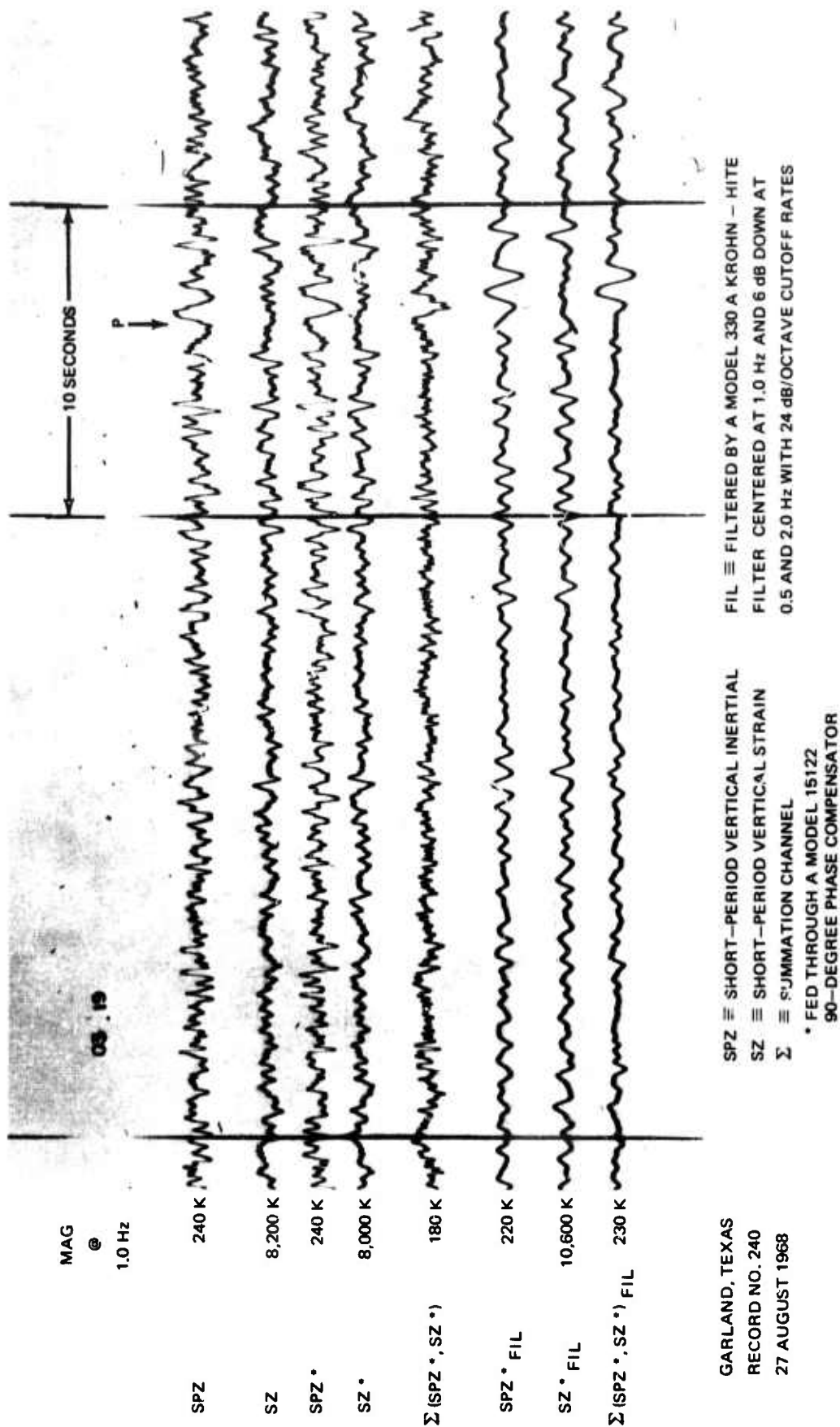


Figure 11. Seismogram showing suppression of low level nighttime noise and enhancement of first motion of P-wave at 031916Z with a vertical strain - vertical inertial seismograph combination at Garland, Texas. Strain and inertial responses are matched to allow cancellation of retrograde Rayleigh waves on the summation traces

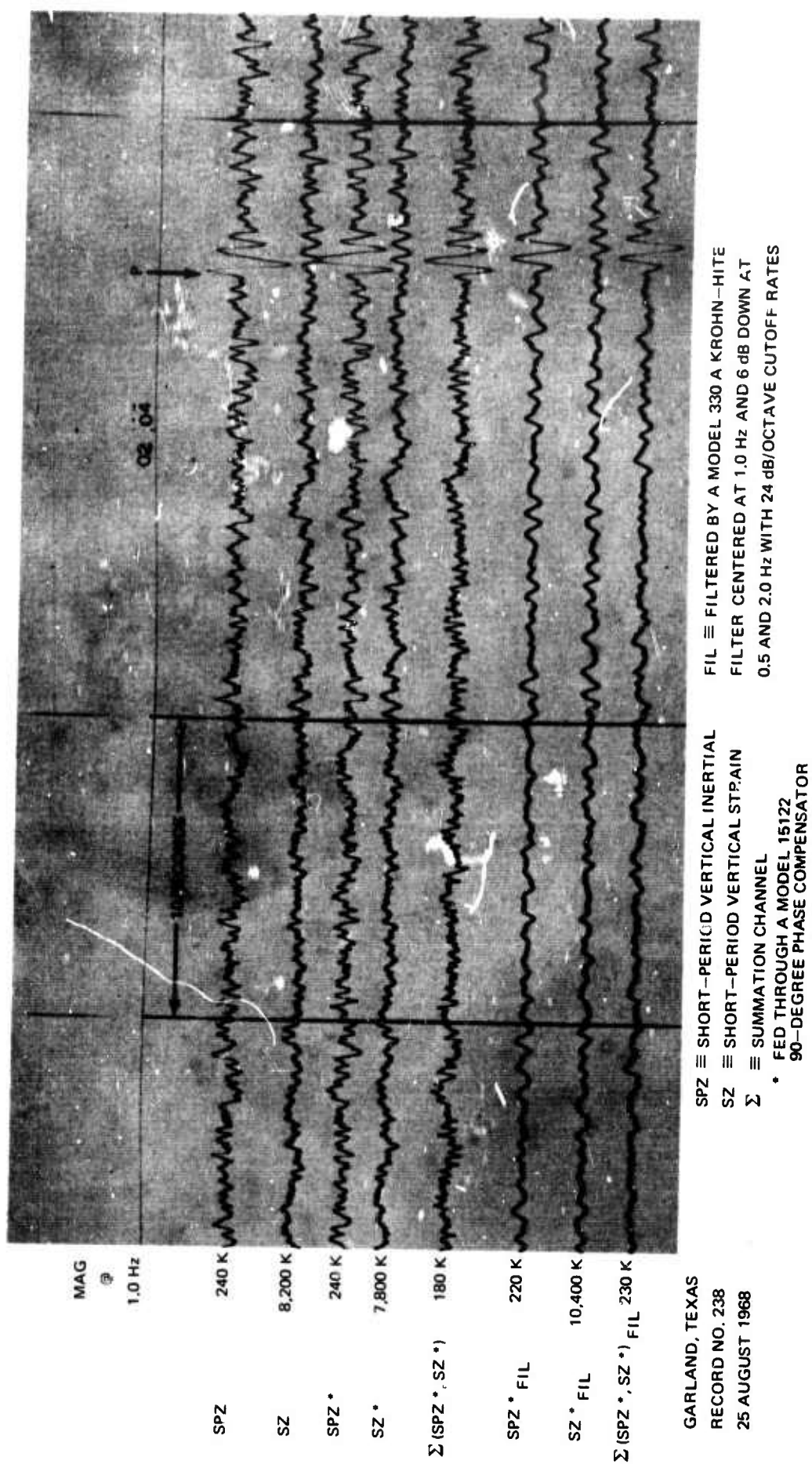


Figure 12. Enhancement of P-wave by suppression of low-level nighttime seismic noise at Garland. The residual noise which limits signal enhancement at present is shown on the bottom trace

APPENDIX 1

STATEMENT OF WORK TO BE DONE

(AFTAC PROJECT AUTHORIZATION NO. VELA T/8704/S/ASD)



STATEMENT OF WORK TO BE DONE  
(AFTAC Project Authorization No. VELA T/8704/S/ASD)

Tasks:

1. Operation:

- a. Routinely operate and maintain the short-period multicomponent strain seismograph system, and the companion pendulum seismographs, at the Wichita Mountains Seismological Observatory (WMSO).
- b. Record seismic data on film and magnetic tapes. Establish a library of seismic data, including records of background noise and signals and appropriate identifying logs, suitable for use in this and other projects.
- c. Evaluate the seismic data collected to determine optimum operating characteristics and adjust the instrumentation accordingly. Establish procedures and maintain quality control to assure collection of high-quality data.

2. Analysis and Investigations:

- a. Analyze data from the strain- and pendulum-seismograph systems to demonstrate further the application of strain seismograph systems to seismic detection and identification problems. This analysis should include, but not necessarily be limited to, the following:

- (1) Investigate the use of multiple-strain/pendulum-input processes for suppressing complex noise fields.

- (2) Study the usefulness of strain- and strain/pendulum-seismograph systems for identifying various types of seismic waves.

- (3) Study the usefulness of strain- and strain/pendulum-seismograph systems in distinguishing between seismic signals from earthquakes and explosions.

- b. Investigate the characteristics and limitations of existing instrumentation and determine possible improvements. Recommend and make modifications as approved by the project office.

- c. Install and operate a vertical strain seismograph with a companion pendulum seismograph at Jarland, Texas.

Operate the installed instruments for a period of nine months and demonstrate the extent of P-wave signal enhancement possible with the strain-pendulum combination.

REPRODUCTION

REPORT OF PROGRESS AGAINST SELECTED MILESTONES (See instructions on reverse before filling in)					1. ARPA ORDER NUMBER 624	
2. PROJECT Short-Period Multicomponent Strain System			3. COMPONENT			
4. NAME AND LOCATION OF PREPARING ACTIVITY Teledyne Industries Inc., Geotech Division 3401 Shiloh Road, Garland, Texas					5. CONTRACT NUMBER F33657-68-C-0948	
					6. REPORT FOR MONTH ENDING 31 August 1968	
CODE a	MILESTONE b	SCHEDULED COMPLETION DATE c	ESTIMATED COMPLETION DATE d	DATE COMPLETED e	REMARKS f	
1	No. 3  Evaluate noise suppression attainable at WMO with (1) a combination of vertical inertial-vertical strain seismographs, (2) a combination of vertical inertial-crossed horizontal strain seismographs.	31 August 1968		31 August 1968		
2	No. 4  Demonstrate the extent of P-wave signal enhancement possible with the strain-pendulum combination at Garland, Texas.	30 Nov. 1968				

TYPED NAME AND TITLE Robert C. Shopland Senior Project Physicist		SIGNATURE <i>Robert C. Shopland</i>		TELEPHONE 214 271-2561	DATE SIGNED 5 Sept 1968
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CLASSIFICATION

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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13. ABSTRACT The P'P'P' phase from a magnitude 8.2 earthquake was enhanced by suppressing 20-sec Rayleigh waves with the short-period vertical strain and vertical inertial seismograph combination at WMO. Signal enhancement by use of a continuous real-time spectral display of suppressed noise at WMO is not feasible in the frequency band 0.2-4.0 Hz because of a lack of time continuity of the spectral windows. True coherence of the seismic noise at WMO in the region of 1 Hz will remain indeterminable unless the ratio of seismic noise to system noise is substantially increased. Seismic noise at Garland, Texas, has been effectively suppressed by a matched combination of vertical strain and vertical inertial seismographs. In three independent series of field tests at WMO using two vertical strain seismometers in separate boreholes, loss of motion between fixed and free ends of the seismometer was approximately the same (22 percent). A comparison of motion produced at the fixed and free ends of the horizontal strain seismometer using an improved calibrator indicates an apparent loss of motion of about 20 percent between end points as compared with losses of 35 to 80 percent measured with the original calibrators.			

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Seismology  
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